Hyper-X Flight Engine Ground Testing for X-43 Flight Risk Reduction

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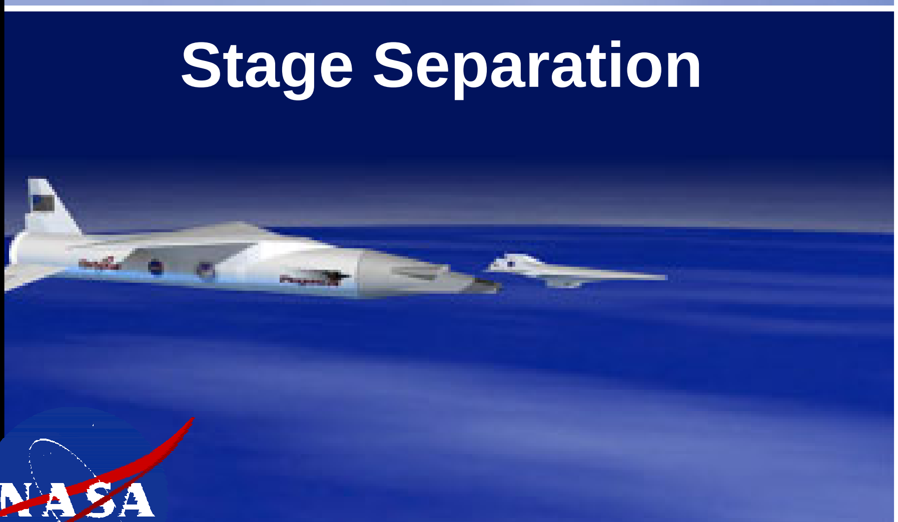
Outline

- X-43 First Flight Key Events
- Presentation Objectives
- Facility Description/Test Conditions
- Model Description
- Test Summary
- Component/Subsystem Verification/Validation
- Test Highlights Video
- Summary

X-43 First Flight Key Mission Events



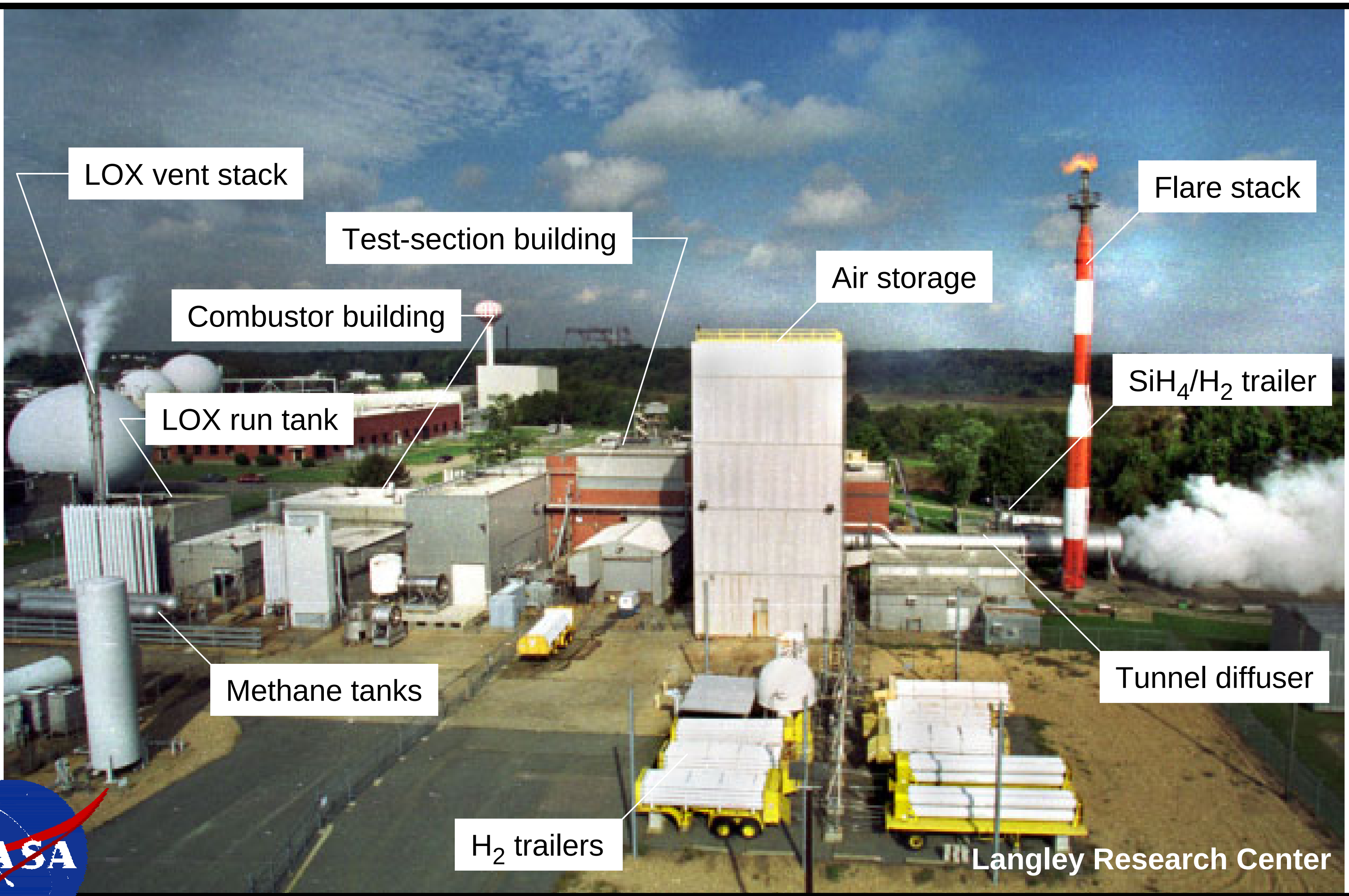
Objectives

- Discuss X-43 components and subsystems that were verified and validated during Mach 7 ground testing in a flight-like environment

- Present relevant data to support success of testing
  - vehicle force and moment increments
  - propulsion/airframe integration

- Present key issues verified in current test that will be addressed in future scramjet-powered vehicle development
  - restart following engine unstart
  - use of ablative TPS in engine flowpath

NASA Langley 8-Foot High-Temperature Tunnel



HXFE/VFS Simulated Freestream Conditions

Simulation	Low q_∞	Flight q_∞	Target Flight	High q_∞
p_{comb} (psig)	1000	1585	atmospheric	2000
T_{comb} (°R)	3350	3350	air	3350
M_∞	6.84	6.92	7.00	6.87
p_∞ (psia)	0.140	0.211	0.204	0.263
q_∞ (psf)	647	1000	1000	1230
T_∞ (°R)	434	423	408	434
H_t (BTU/lb_m)	1064	1052	1052	1064

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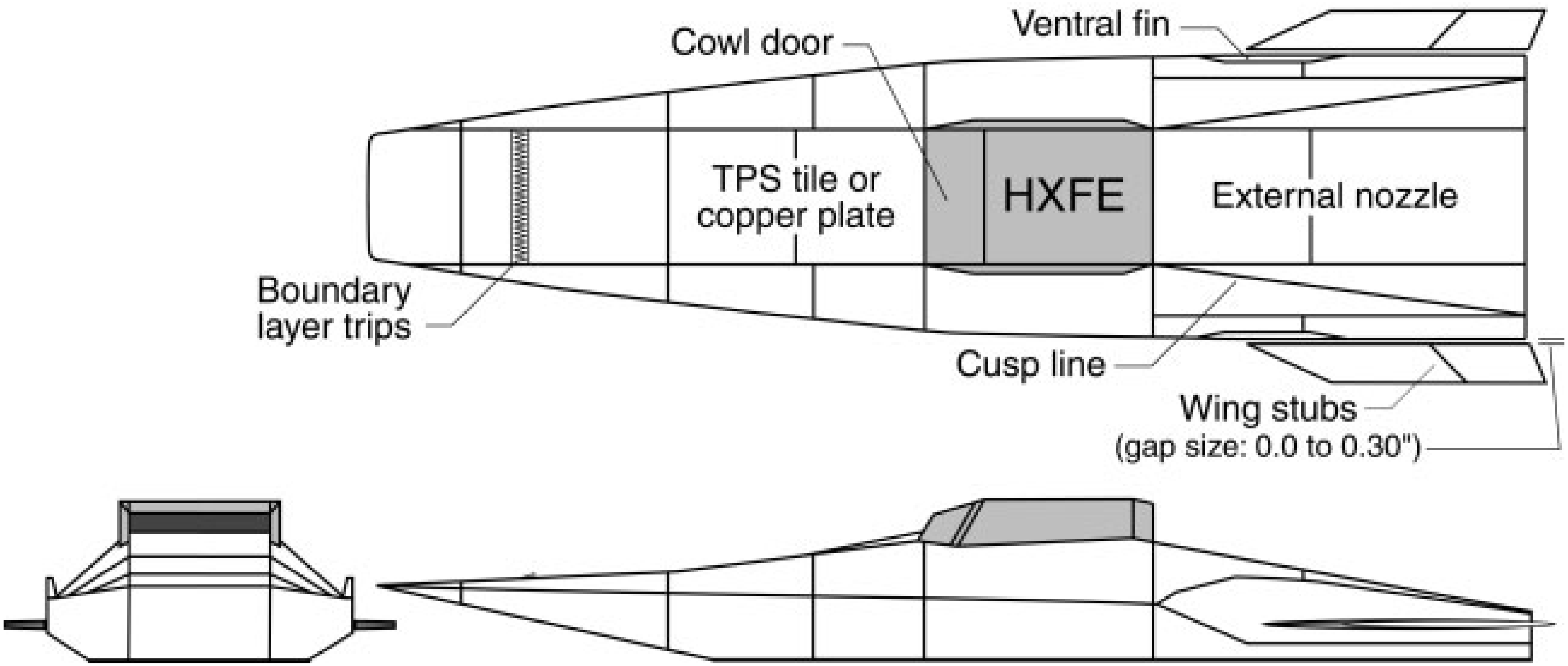
Hyper-X Flight Engine/Vehicle Flowpath Simulator (HXFE/VFS)



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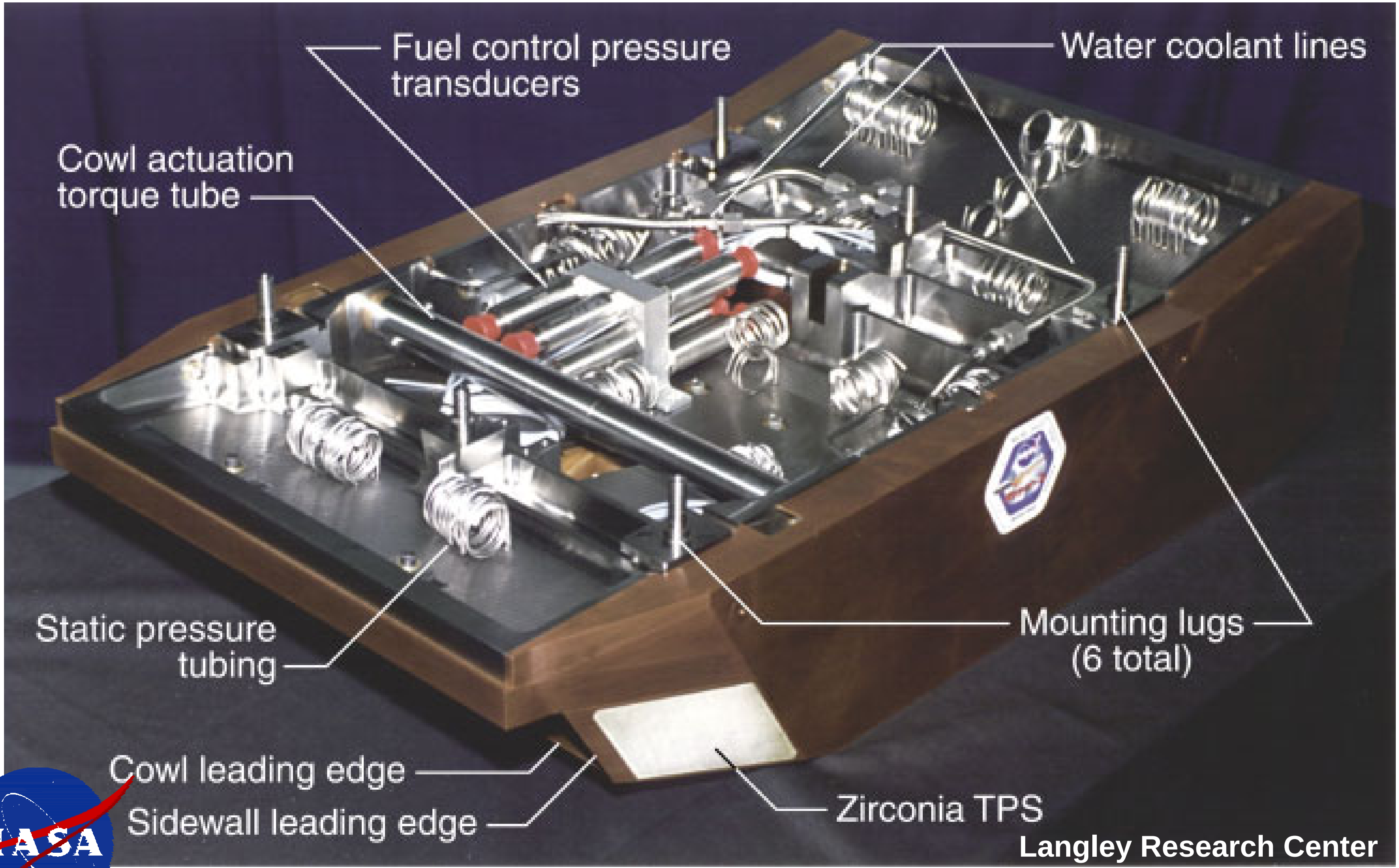
HXFE/VFS Installation Image

Mach 7 Hyper-X Flight Engine Image



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Test Summary

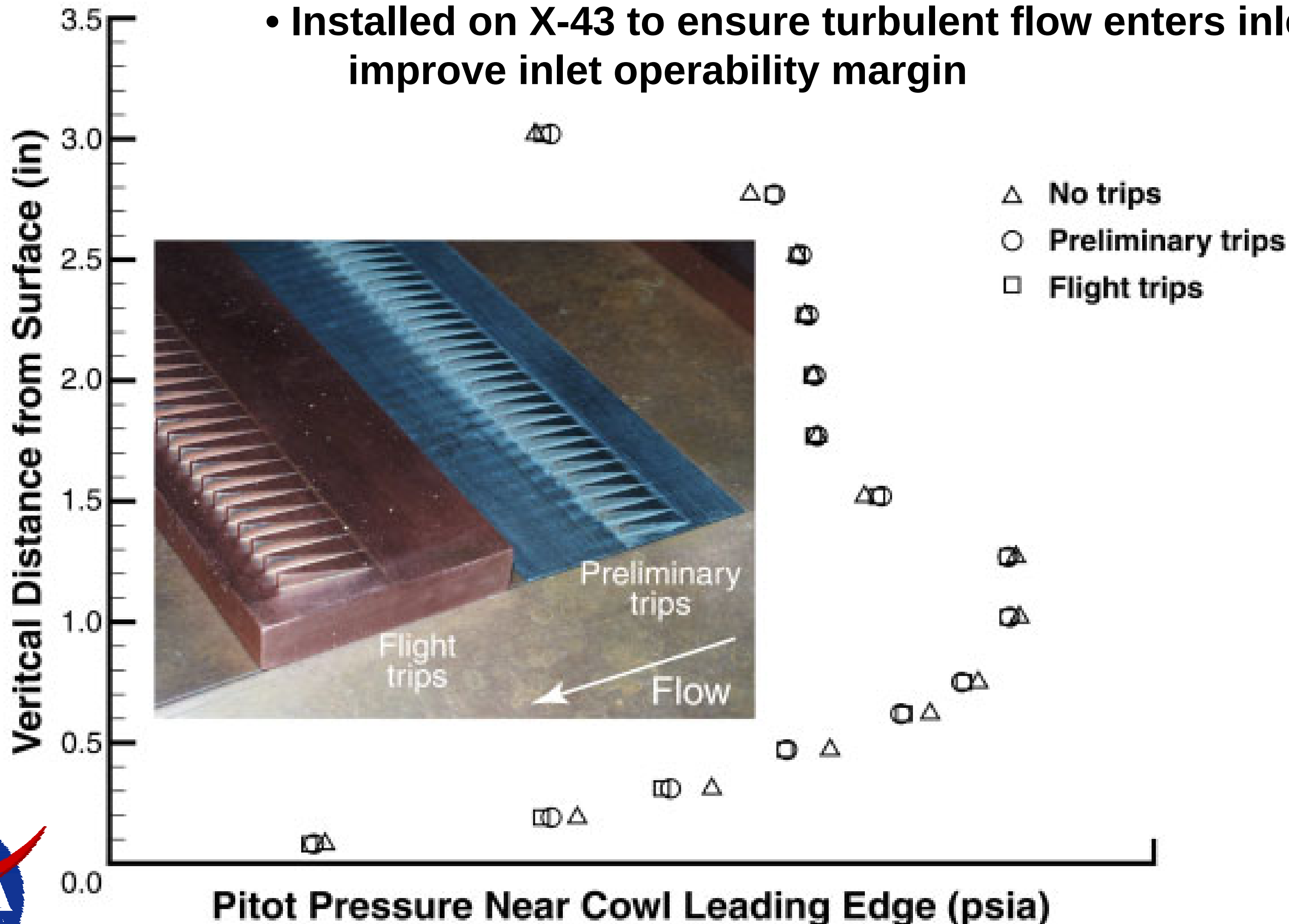
- Installation in tunnel began August 4, 1999
- First successful run on August 25, 1999
- Fourteen unfueled runs
  - inlet flowfield characterization
  - cowl-door actuation
- Forty fueled runs
  - engine performance and operability
  - closed-loop active feedback control for flight engine fueling
  - boundary-layer effects (thermal and geometric)
  - dynamic pressure effects
  - angle of attack (0°, 2°, 4°) and sideslip angle (0°, 1°, 3°) effects
  - engine unstart/restart capability

HXFE/VFS Flight/Flight-like Subsystems

- Forebody Boundary-layer Trips
- AETB-12 TPS Tiles on Forebody
- Engine Integrity
- Cowl and Sidewall Leading-Edge Cooling
- Cowl Actuation and Inlet Starting
- Longitudinal Wing-Gap Heating
- Propulsion Subsystem Control (PSC)
  - Hardware and Software Requirements
    - Control System
    - Ignitor and Fuel System
    - Flowpath Sensors
  - Control Law Verification
    - Ignition and Transition to Hydrogen Fuel
    - Engine Unstart Prevention

Forebody Boundary-Layer Trips

- **Installed on X-43 to ensure turbulent flow enters inlet to improve inlet operability margin**



Forebody TPS and Engine Leading-Edge Cooling

- **AETB-12 TPS Tiles**
  - same material covers majority of X-43
  - withstood multiple exposures to flight-like aerothermal loads with no degradation
  - successful pre-test flight-like tile repairs
  - flight-like instrumentation installation and data acquisition

- **Engine Leading-Edge Cooling**
  - cowl and sidewalls
  - cooling passages identical to X-43
  - identical pressure and mass flow rate to X-43
  - no problems encountered

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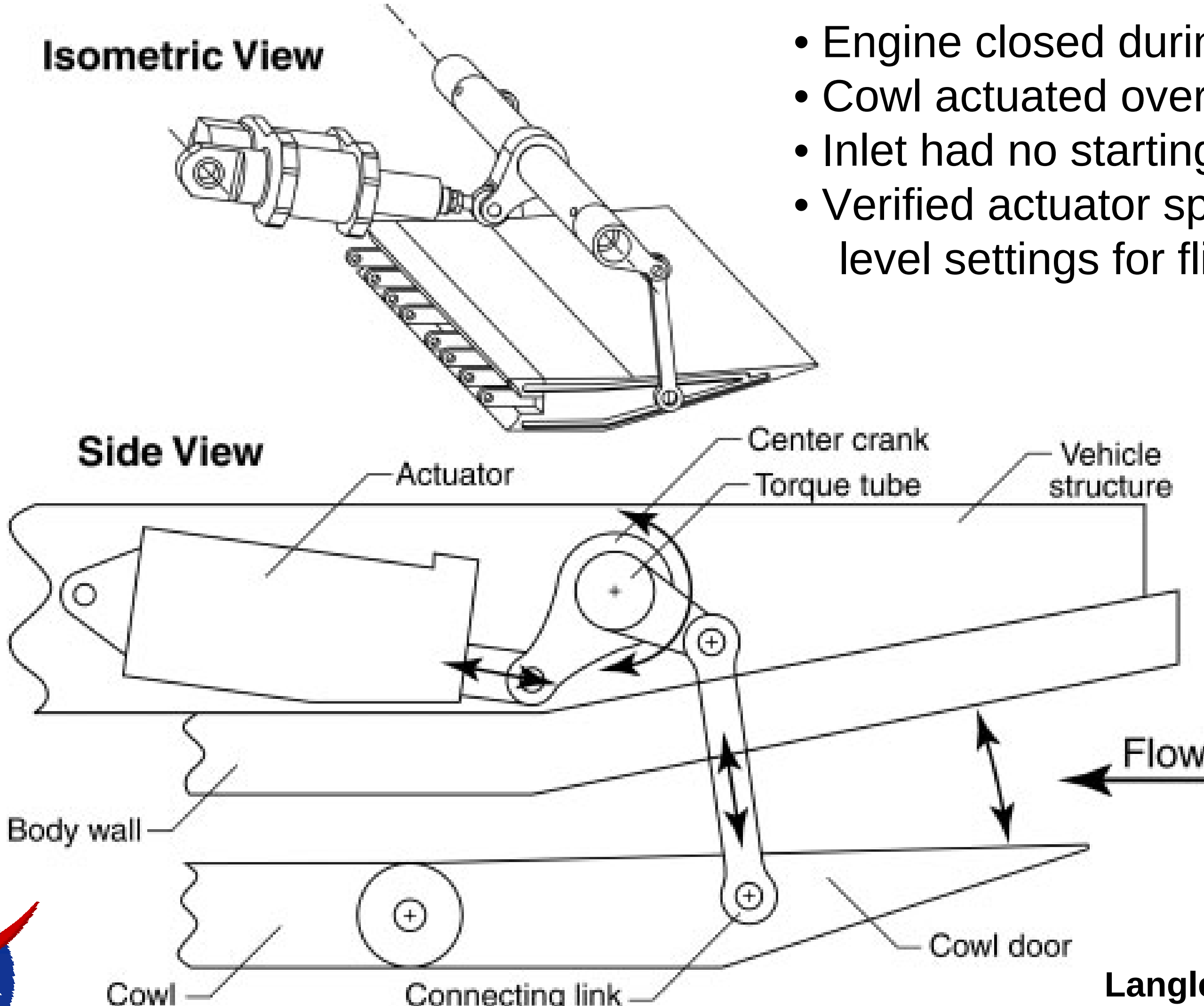
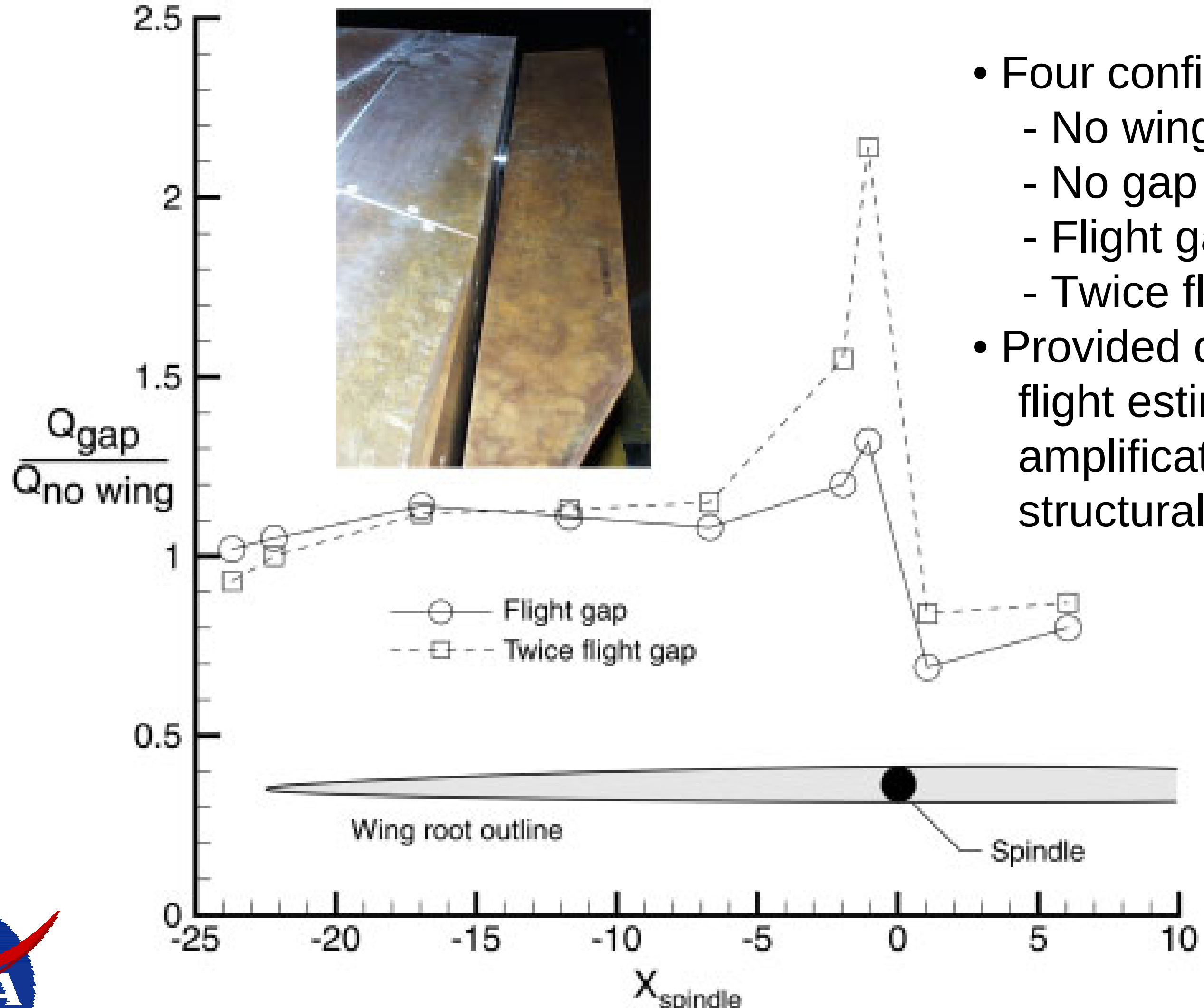
Cowl Actuation and Inlet Starting



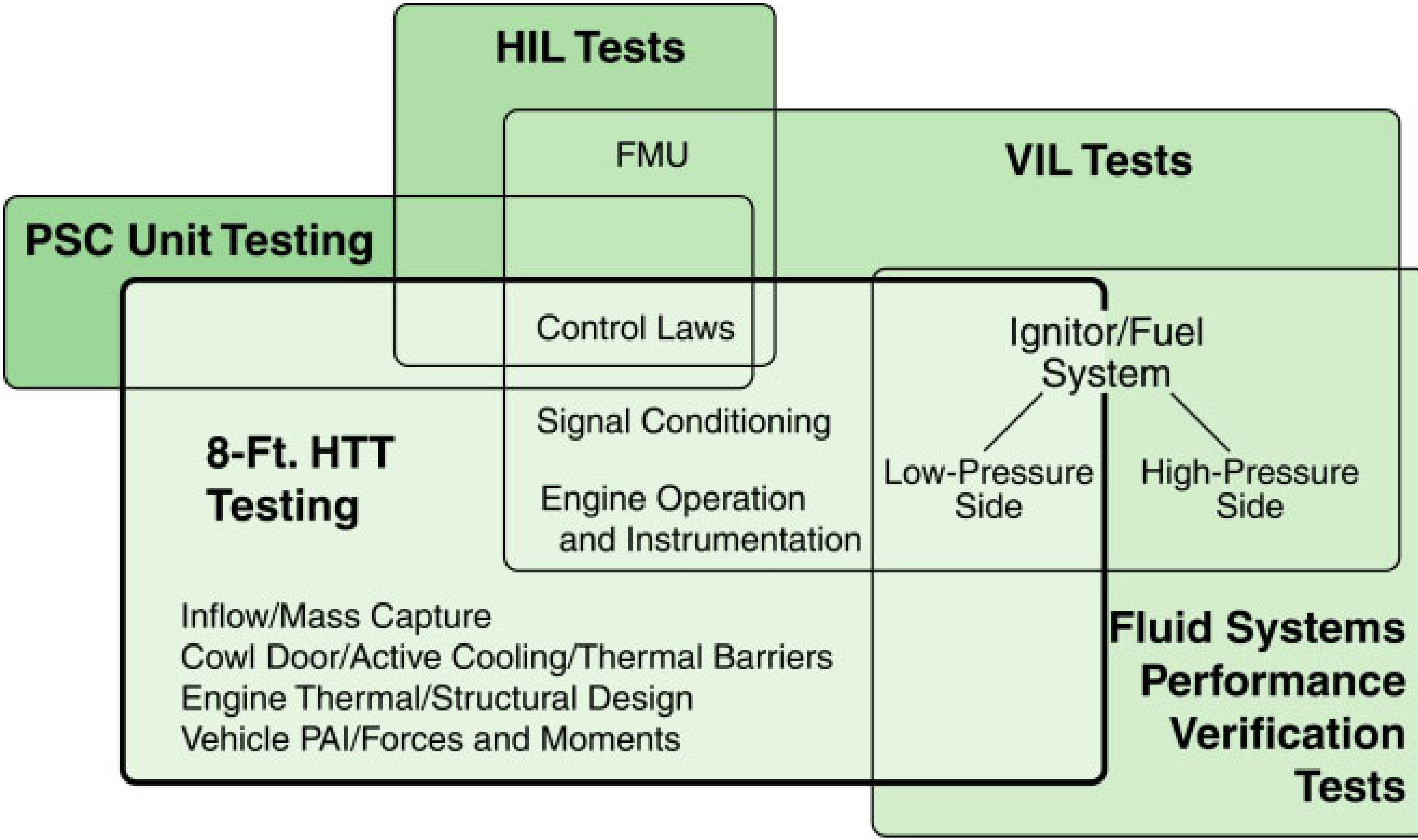
- Engine closed during ascent
- Cowl actuated over 400 times
- Inlet had no starting problems
- Verified actuator speed and torque level settings for flight

Longitudinal Wing-Gap Heating



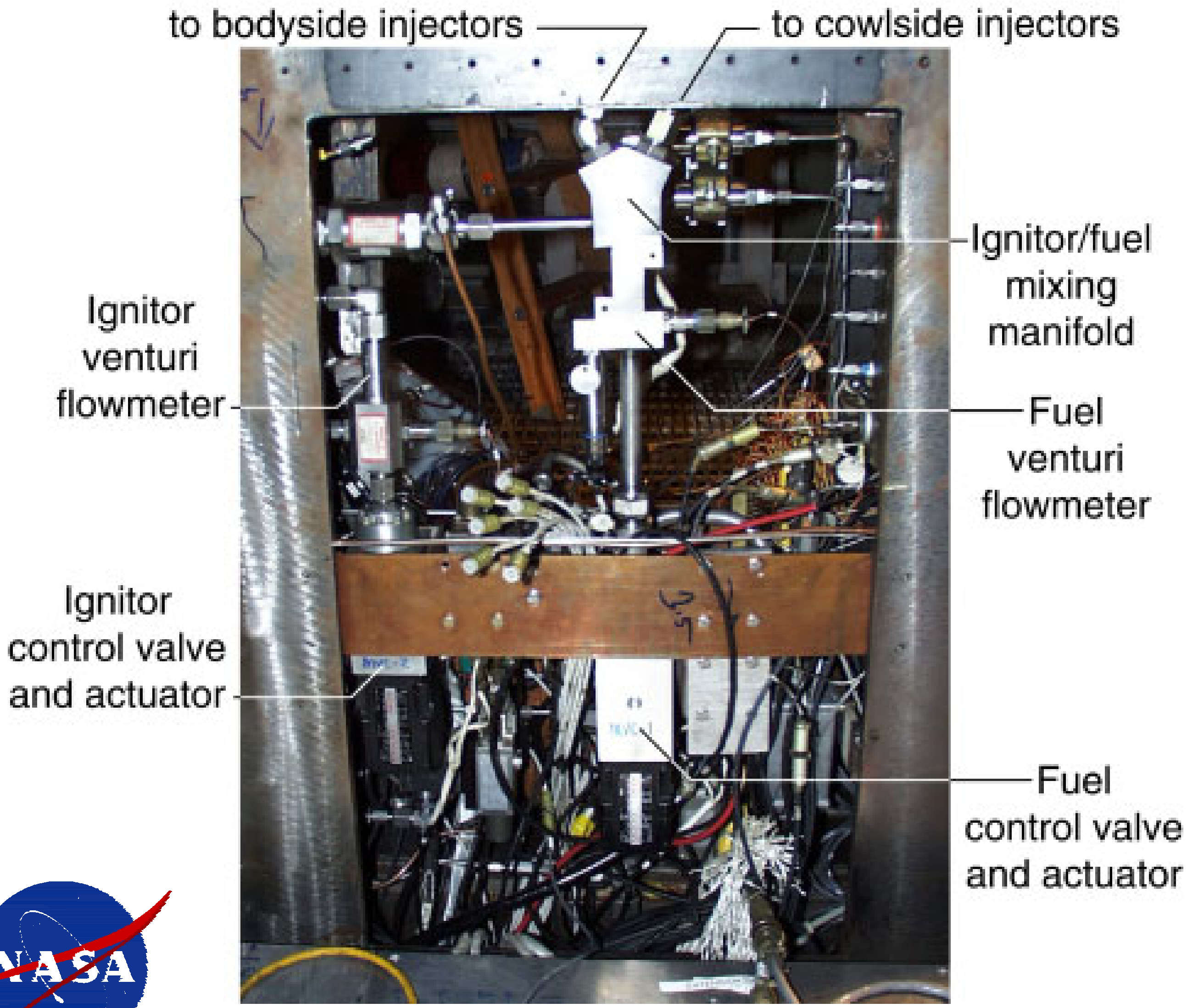
- Four configurations tested:
  - No wing
  - No gap
  - Flight gap
  - Twice flight gap
- Provided data to confirm flight estimates for heating amplification applied to structural design

PSC Development, Verification, and Validation



- **Ensures thorough testing of subsystem hardware and software elements**

Ignitor and Fuel System



- **Low-pressure side**
- **Flight-like:**
  - Plumbing
    - Line lengths
    - Line diameters
    - Fittings
  - Control valves
  - Flowmeters
  - Sensors
  - Fuel injectors
  - Delivery pressures

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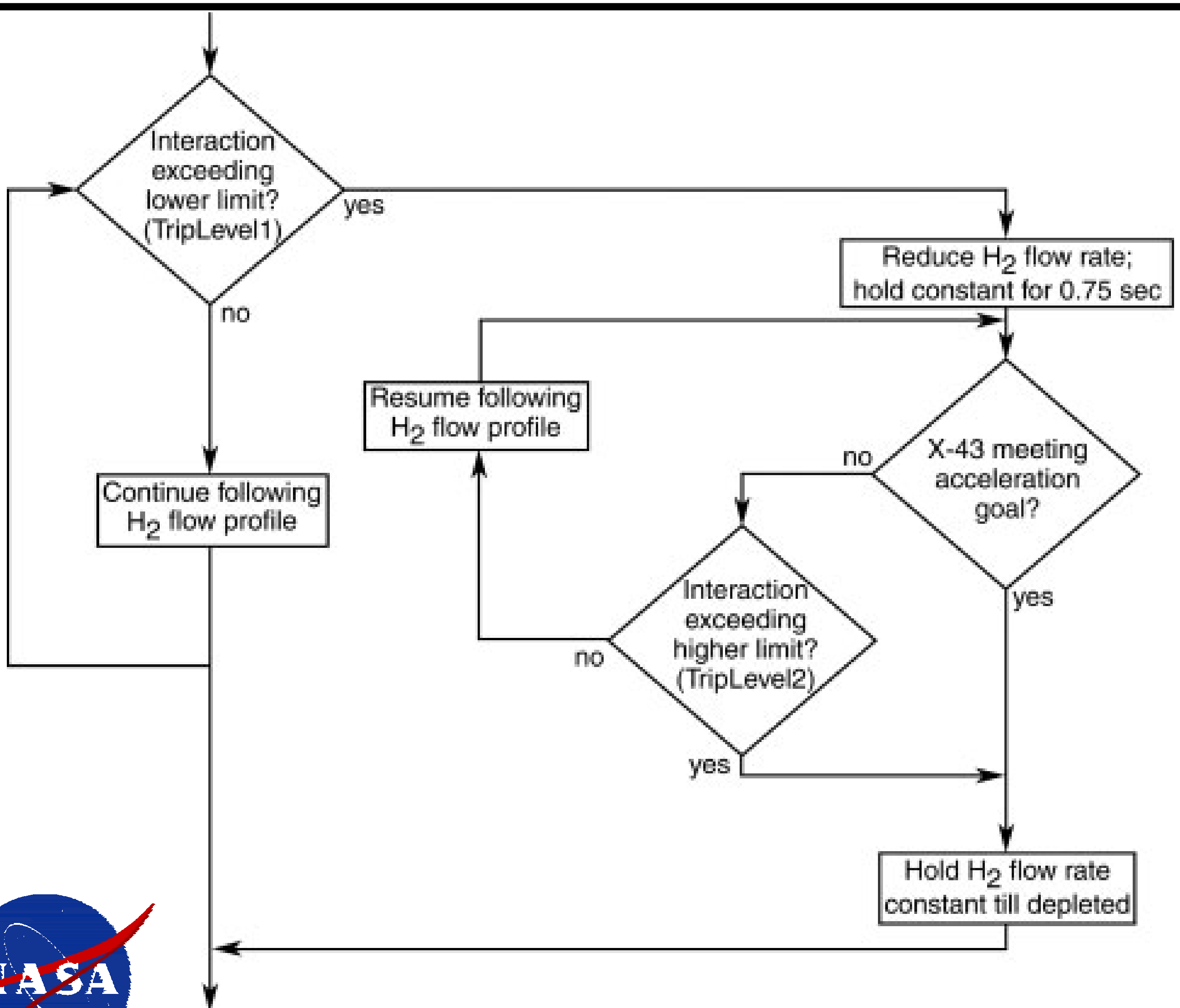
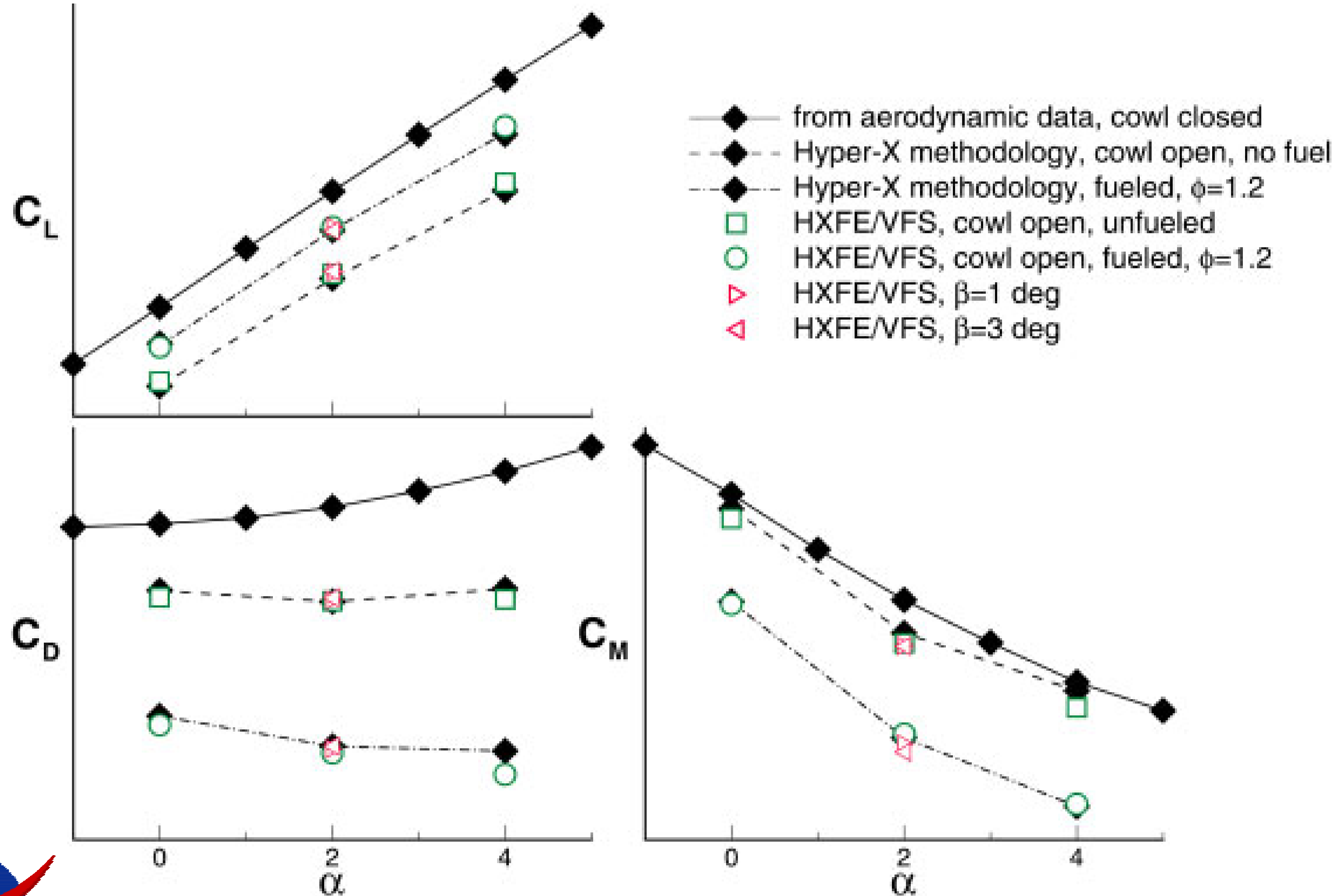
Engine Unstart Prevention



- Maximize probability of achieving acceleration goal
- Guard against engine unstart

X-43 Force and Moment Increments



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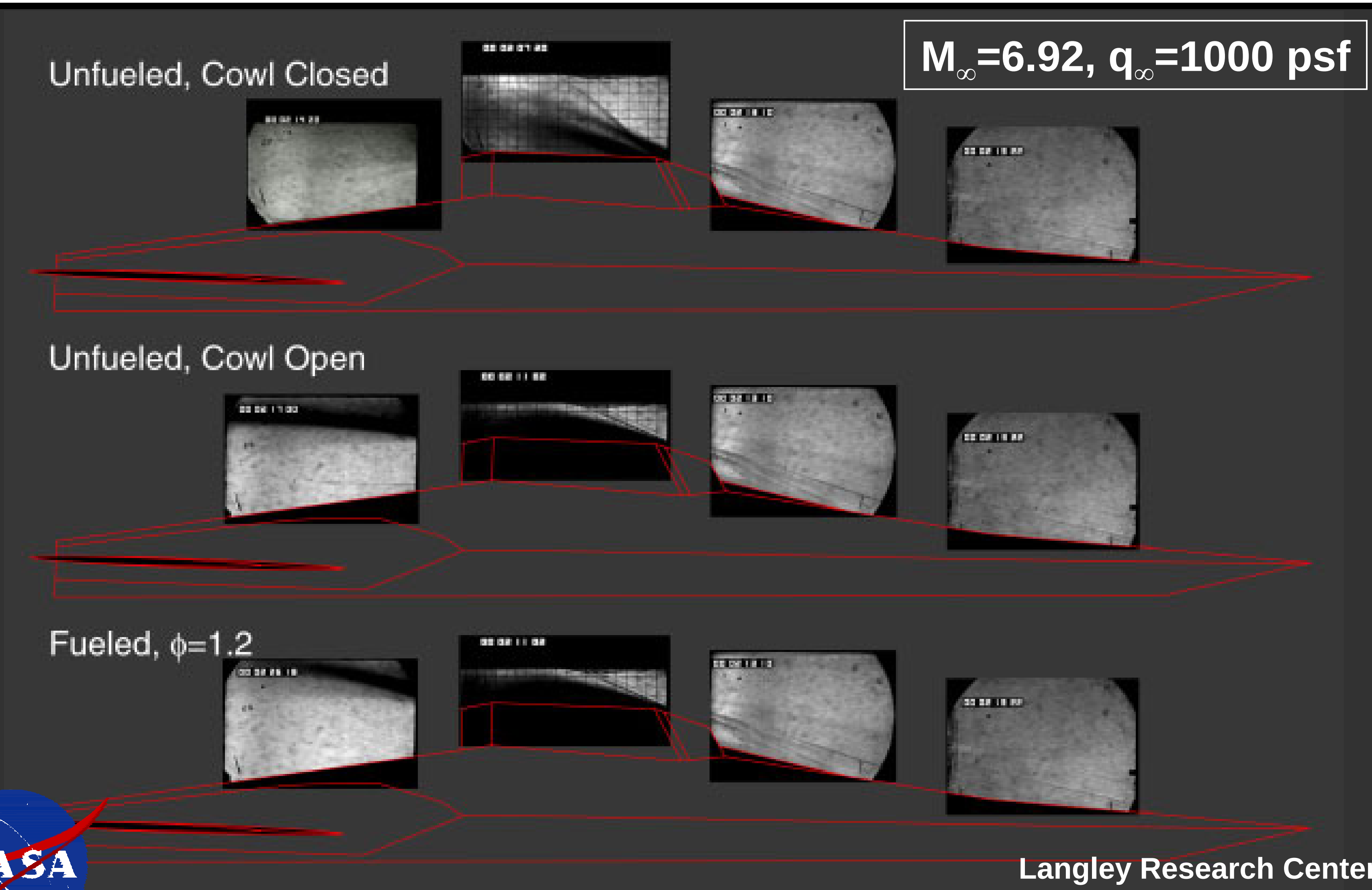
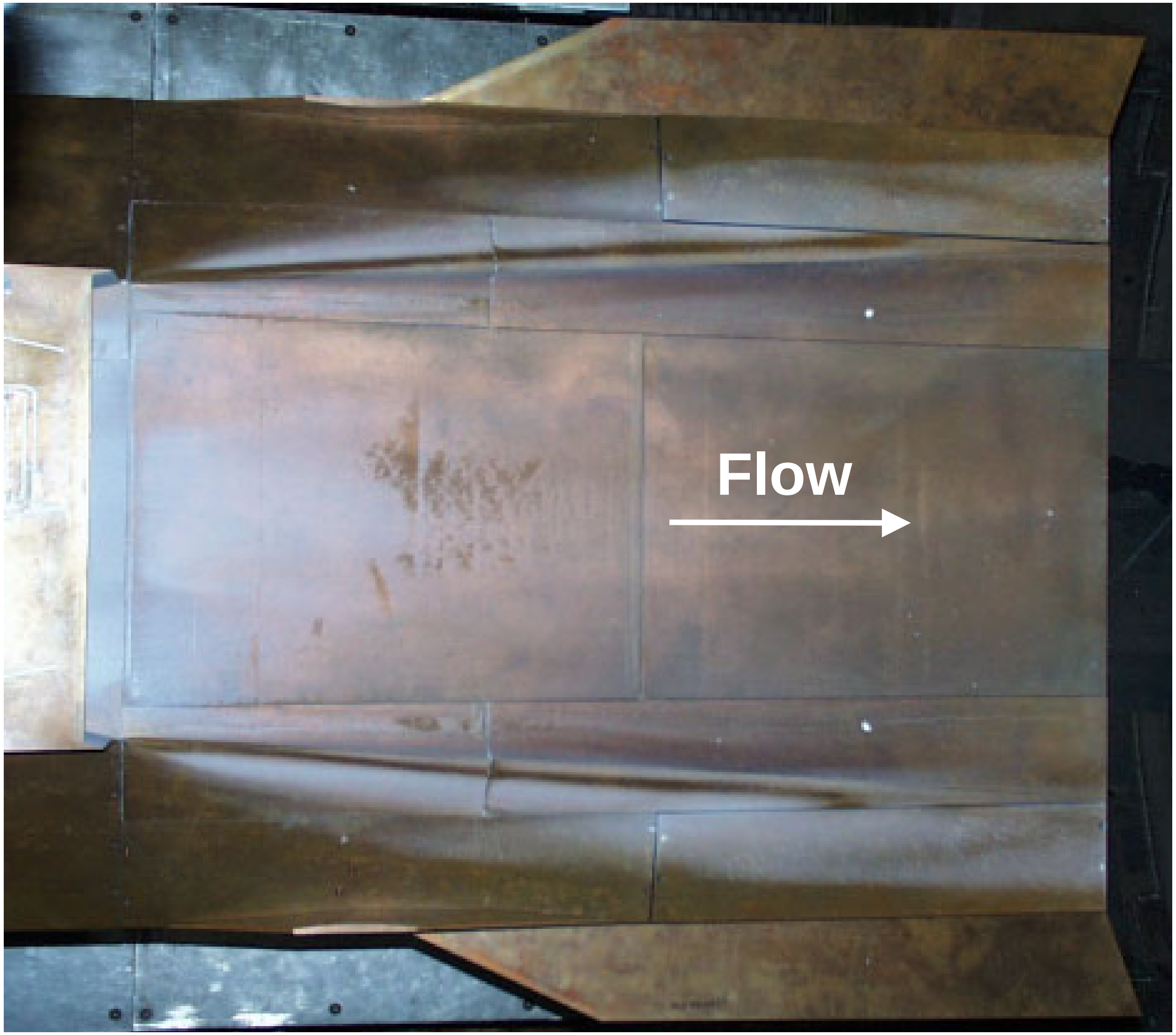
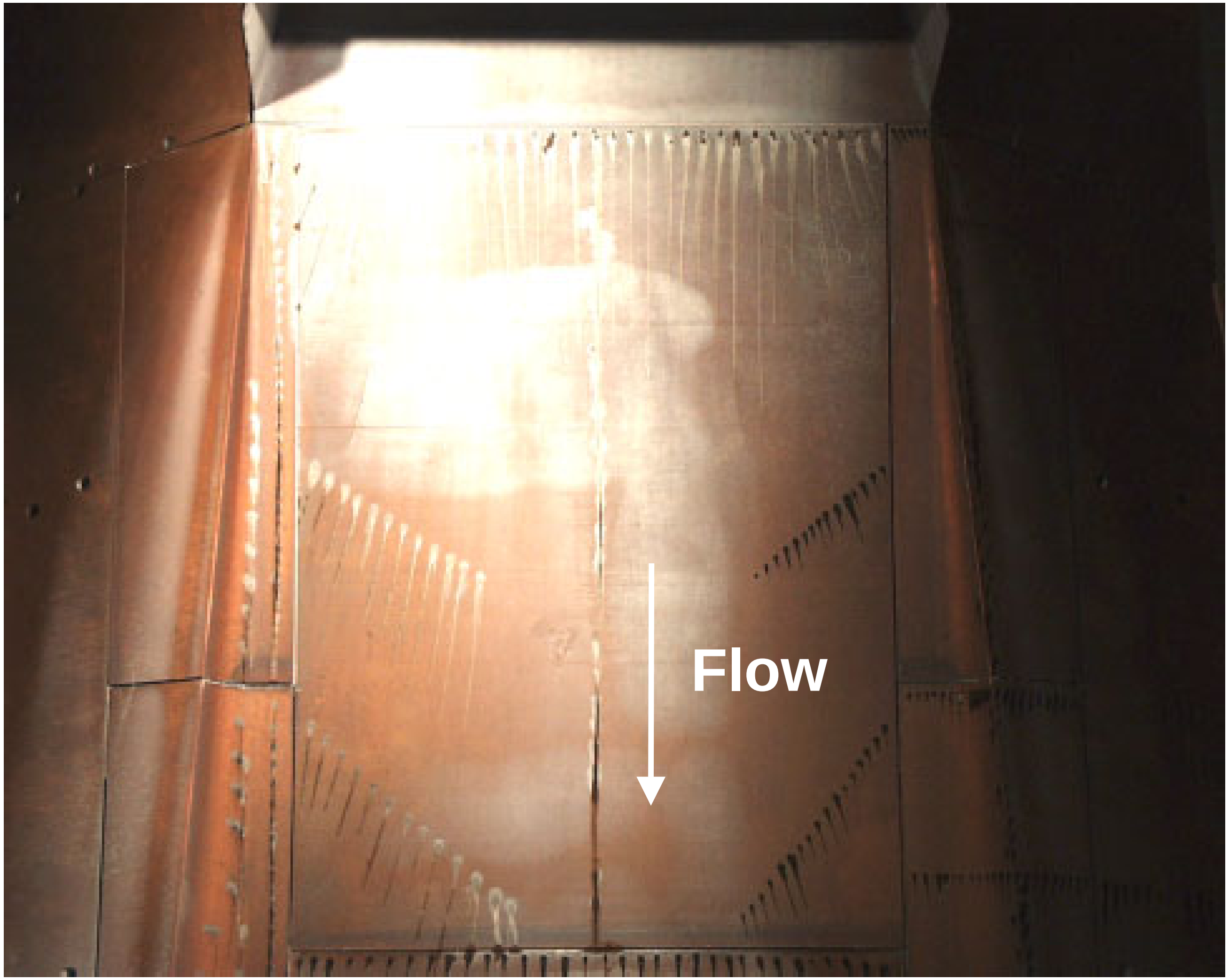
HXFE/VFS Composite Schlieren Images



Aftbody SiO_2 Deposits

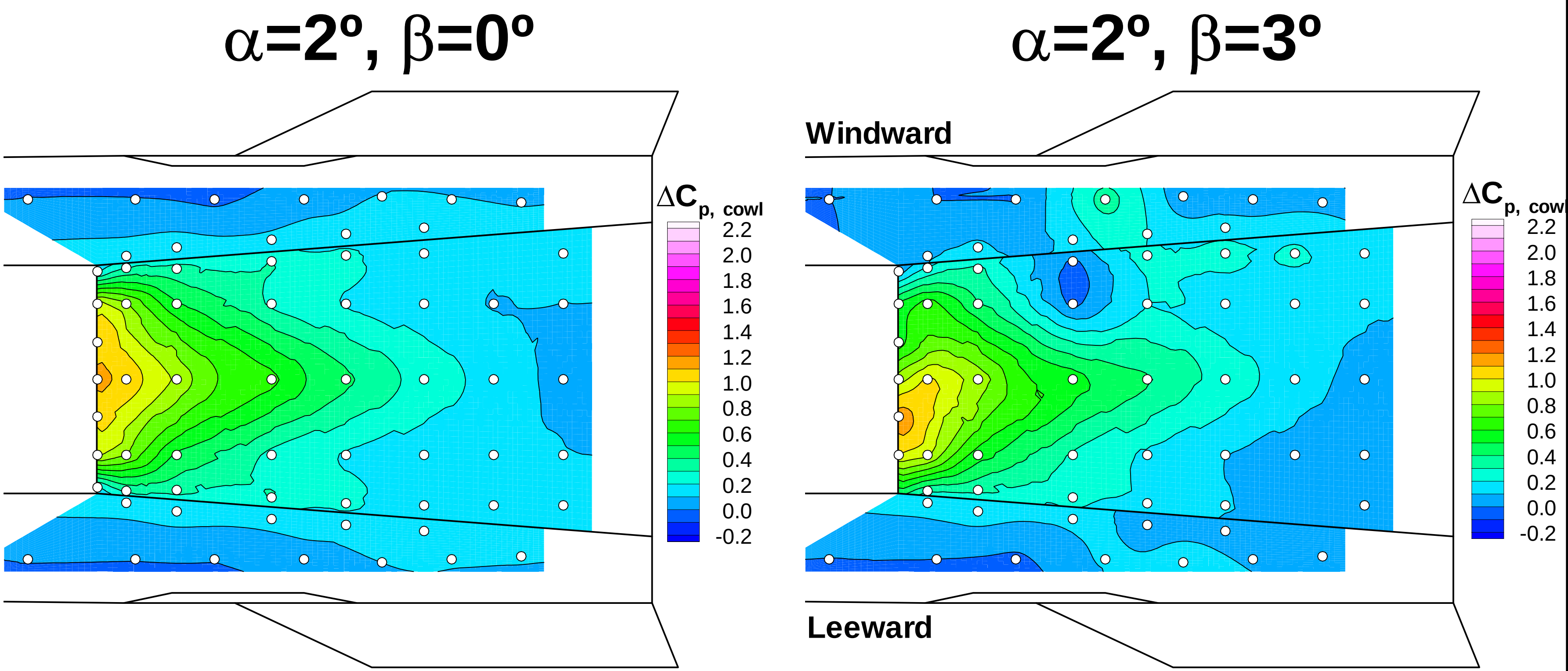


Aftbody Oil-Flow Patterns



Aftbody ΔC_p Due to Cowl Opening

M_∞=6.92, q_∞=1000 psf



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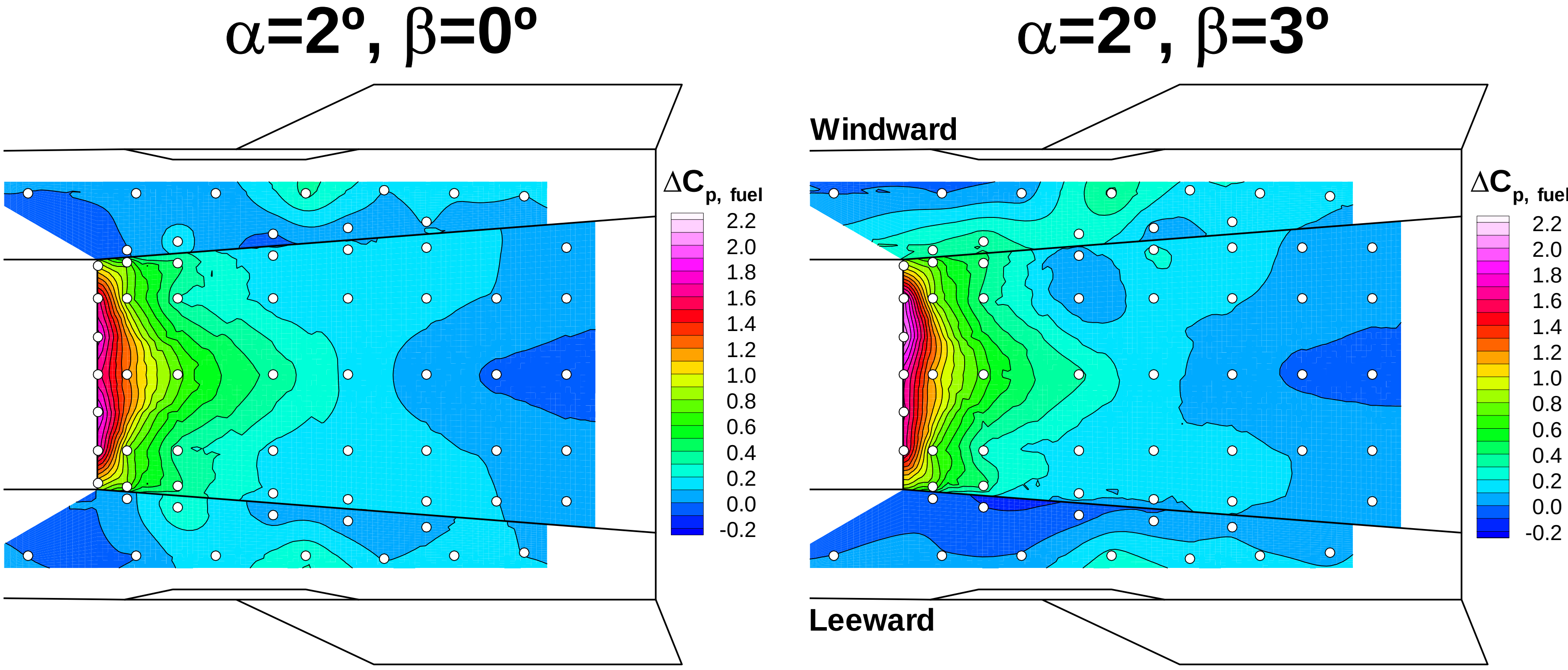
Aftbody ΔC_p Due to Fueling

M_∞=6.92, q_∞=1000 psf



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Pre- and Post-Run BLA-20 TPS Images